A Meta-Analysis of Mental Time Travel Impairments in Autism Spectrum Disorders

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Abstract

Individuals with autism spectrum disorders (ASD) have a wide range of cognitive impairments. Mental time travel (MTT) is the ability to mentally re-experience past events and pre-experience possible future events. Studies have shown MTT impairments in individuals with ASD, however, these findings may be confounded by a number of factors including verbal ability to report MTT, factors related to MTT task and demographic factors of participants. The present study provided a meta-analysis on MTT deficits in individuals with ASD and examined the potential moderating variables for these impairments. Twenty-six studies were included, and the participants comprised 667 individuals with ASD and 671 healthy controls. Results showed significant overall MTT impairments (Cohen's d = −0.95) in individuals with ASD. Moderator and meta-regression analyses revealed that verbal IQ was significantly related to MTT impairments; type of MTT, type of task, measurement indices of MTT, age of participants, gender ratio and full IQ did not explain the MTT impairments. These findings suggest that MTT is severely impaired in individuals with ASD, verbal IQ contributed to MTT impairments, and task characteristics did not affect the degree of impairments.

Keywords: Mental time travel, Autism spectrum disorder, Autobiographical memory, Episodic future thinking, Meta-analysis

1. Introduction

Autism spectrum disorders (ASD) is one of the neurodevelopmental disorders characterized by persistent difficulty in social interaction and communication, restricted repetitive behavior and/or stereotyped interest, and language impairment (American Psychiatric Association, 2013). Individuals with ASD also exhibit a wide range of cognitive impairments including social cognition and executive function (Kristen, Rossmann, & Sodian, 2014; Lind, Williams, Bowler, & Peel, 2014; Wang et al., 2017). Mental time travel (MTT) is one of the cognitive functions that enable us to re-experience past personal events (autobiographical memory, AM) and pre-experience possible future events (episodic future thinking, EFT) through mental simulation (Brocas & Carrillo, 2018; Stawarczyk & D'Argembeau, 2015; Suddendorf & Corballis, 1997). MTT is important in daily life since it plays an important role in coping, emotion regulation, decision making and problem solving (Brocas & Carrillo, 2018; D'Argembeau, Renaud, & Van der Linden, 2011; Schacter & Madore, 2016).

MTT impairments have been observed in psychiatric disorders such as schizophrenia-spectrum disorders (D'Argembeau, Raffard, & Van der Linden, 2008), major depressive disorder (Berna et al., 2016; Liu, Li, Xiao, Yang, & Jiang, 2013) , post-traumatic stress disorder (Ono, Devilly, & Shum, 2016), and ASD (Crane, Lind, & Bowler, 2013). While most studies in ASD revealed MTT impairments in these individuals, including generating less specific AM and EFT (Lind, Williams, et al., 2014) and reporting fewer details in AM and EFT (Chaput et al., 2013; Terrett et al., 2013) compared with healthy controls, inconsistent results have also been reported. For

example, Crane et al. (2013) did not find AM impairment in individuals with ASD. Ciaramelli et al. (2018) found individuals with ASD showed more severe impairments in EFT than in AM, while Lind and Bowler (2010) and Lind, Bowler, and Raber (2014) found individuals with ASD showed similar impairments in AM and EFT. Findings on MTT in ASD may be confounded by a number of factors including verbal ability to report MTT, type of MTT (AM or EFT), type of task, indices used to measure MTT, and demographic variables. The present meta-analysis therefore was designed to examine the degree of MTT impairment and impact of these factors on MTT performance in ASD.

Most of the MTT measures require verbal report of recalled and imagined scenarios, thus language ability is the basic requirement for MTT performance. Given that language impairment is one of the core deficits in ASD, verbal ability may be related to MTT impairments in these individuals (Marini et al., 2016). Though the majority of studies matched verbal or narrative ability between ASD and control groups (Bang, Burns, & Nadig, 2013; Goddard, Dritschel, Robinson, & Howlin, 2014; Maister, Simons, & Plaisted-Grant, 2013), narrative ability was found to be significantly correlated with EFT performance in both typically developing and ASD children (Marini et al., 2018). However, whether verbal IQ was correlated to MTT impairments in ASD is an important issue that is under-studied by previous researches, the present study would examine this issue.

Theoretically, AM and EFT are closely related. Performance of AM and EFT are significantly correlated in healthy population (Addis, Wong, & Schacter, 2007;

D'Argembeau, Raffard, & Van der Linden, 2008; Schacter & Madore, 2016) and ASD individuals (Lind & Bowler, 2010). AM and EFT also share similar scene construction (Schacter & Addis, 2007) and self-projection (Lind, Bowler, & Raber, 2014) processes. However, EFT may need additional processes to recombine and reconstruct elements from AM into novel and integrative events that might happen in the future (Gilmore et al., 2018; Schacter et al., 2007). Whether individuals with ASD show differentiated impairments in AM and EFT remains unclear and we, therefore, examine the type of MTT as a moderator in the present meta-analysis.

Studies adopted different tasks and used different indices when measuring MTT. The commonly used tasks include the cue word task (sometimes referred to as Autobiographical Memory Test) (Crane, Goddard, & Pring, 2009; Crane, Pring, Jukes, & Goddard, 2012; Robinson, Howlin, & Russell, 2017) and Autobiographical Memory Interview (Crane & Goddard, 2008; Kristen et al., 2014; Tanweer, Rathbone, & Souchay, 2010). In the cue word task, participants were required to generate specific events from personal memories or possible future events related to cue words. The main indice used in this task is specificity. A specific event is an event happening at a specific place and time and lasting no more than one day. In the Autobiographical Memory Interview, participants were required to generate personal AM and EFT events during specific life periods. For example, Crane and Goddard (2008) required participants to generate AM from four time periods (before age of 5; ages 5 to 11; ages 11 to 16; ages 16 to 21). In this test, the main indices used were the number of details, specificity and experiential index (e.g., vividness and emotionality) (Chaput et al., 2013; Kristen et al.,

2014). Crane et al. (2013) used the Autobiographical Memory Interview and did not find MTT impairments in ASD, while Tanweer et al. (2010) used a cue word task and found that individuals with ASD showed deficits in both AM and EFT. Whether the inconsistent results were contributed by differences in tasks or indices needs to be examined.

The demographics of participants such as age and gender have been suggested to show a significant effect on MTT performance. Abram, Picard, Navarro, and Piolino (2014) found that MTT performance showed an inverted U shape across the lifespan in healthy participants, i.e., improved from 6 to 21 years and declined from 62 to 81 years. AM has been studied in individuals with ASD across the lifespan including children, adolescents and adults (Ciaramelli et al., 2018; Crane & Goddard, 2008; Goddard, Dritschel, & Howlin, 2014). Adults with ASD generated less detail and fewer specific memories than control groups (Tanweer et al., 2010), While children and adolescents with ASD showed mixed results. Most studies found that ASD children and adolescents generated fewer specific AM or EFT and with fewer details than healthy controls (Goddard et al., 2014a; Hanson and Atance, 2014), however, several studies indicated that these ASD individuals did not exhibit impairments in MTT (Crane et al., 2013; Robinson et al., 2017). In addition, Goddard, Dritschel, Robinson, and Howlin (2014) found that females had better performance (i.e., more details) than males in AM for both ASD and typically developing children.

Taken together, the present study was to conduct a meta-analysis on MTT in individuals with ASD. In particular, we aimed to examine the impact of verbal ability

(indexed by verbal IQ) on MTT in ASD, we also examined the effect of type of MTT, type of task, indices used to measure MTT, and demographics of participants such as age, gender, and full IQ upon MTT performance in ASD. We hypothesized that individuals with ASD would show significant MTT impairments. Verbal IQ would be related to MTT impairments. Individuals with ASD would show impairments in both AM and EFT. The MTT deficits in individuals with ASD were stable in different tasks and with different indices.

2. Method

2.1. Literature search

A literature search in Web of Science, PubMed and Elsevier was conducted with the following keywords: (autism OR ASD OR Autism Spectrum Disorders OR Asperger OR HFA OR high functioning autism) AND (mental time travel OR past thinking OR AM OR autobiographical memory OR remembering the past OR future thinking OR prospection OR foresight OR future simulation OR imaging the future OR future directed thinking OR imagined future). The literature search was from 1972 to July 30, 2018.

The literature search was restricted to peer-reviewed papers. A total of 645 potential papers were identified from the literature search and an additional 31 papers were identified though reference lists from review articles. After excluding irrelevant articles based on title and abstract and removing duplications, 45 papers remained for further consideration. Next, studies were included if the following criteria were met:

a) Studies were reported in English; b) Studies were not reviews, comments, or meta-analyses; c) Individuals with ASD were diagnosed with formal diagnostic criteria, e.g., International Classification of Diseases (ICD; (World Health Organization., 1992)); Diagnostic, Statistical Manual of mental disorders (DSM; (American Psychiatric Association., 2000, 2013)); the Autism Diagnostic Interview-Revised (ADI-R; (Lord, Rutter, & Le Couteur, 1994)); the Autism Diagnostic Observation Scale (ADOS; (Lord et al., 2000)); Autism Diagnostic Observation Schedule-Generic (Lord et al., 2000), Autism Diagnostic Observation Schedule-2nd edition (Lord et al., 2012) and the Asperger Syndrome Diagnostic Interview (ASDI; (Gillberg, Gillberg, Rastam, & Wentz, 2001)) etc.; d) Studies compared individuals with ASD with healthy controls; e) Studies measured AM or EFT or both; f) Studies reported sufficient data to calculate effect size. For the studies fulfilling previous criteria but without sufficient data to calculate effect size, we contacted the authors to provide additional data. If no further data were provided, the studies were excluded from the final analysis. As a result, 26 papers were included in the meta-analysis. The process of literature screening is shown in Fig. 1.

INSERT FIG 1 HERE

2.2. Data extraction

For each included paper, the following data were extracted: First, the basic information of a study such as the first author and the year published. Second, information of the participants such as diagnosis, sample size, mean age, mean full

and verbal IQ, and gender ratio. Third, data for calculating effect sizes on group differences of MTT. Mean and SD on measures of MTT were extracted; if mean and SD were not available, other data that could be used to calculate effect sizes such as t-values and sample size were extracted. Fourth, the type of MTT (AM, EFT) was recorded. Four studies measured both AM and EFT, these papers had an overall effect size by averaging those of AM and EFT for the overall MTT analysis; in the moderator analysis, the effect sizes on AM and EFT were calculated separately (Chisholm et al., 2018; Lind, Bowler, et al., 2014; Raffard et al., 2010). Fifth, the type of task used to measure MTT (cue word task, Autobiographical Memory Interview) was recorded. Two studies used both measures to assess AM, these papers had an overall effect size by averaging those of the two measures; in the moderator analysis, their effect sizes were calculated separately (Crane et al., 2013; Goddard, Dritschel, & Howlin, 2014; Goddard, Dritschel, Robinson, et al., 2014). Sixth, the outcome indices of MTT (number of details/specificity/experiential index[1]) was recorded. Four papers provided more than one index for the same type of MTT (Crane, Goddard, & Pring, 2010; Goddard, Dritschel, & Howlin, 2014; Raffard et al., 2010; Robinson et al., 2017), and these papers had an overall effect size; in the moderator analysis, each index were calculated separately. In addition, three studies used nonverbal test to measure future thinking, and could not be classified to these task types and indices, thus these three studies were excluded in these two moderator analyses (Ferretti et al., 2018; Marini et al.,

[1] Experiential index included different measures such as emotion, sensory details, vividness, important intensity etc. A non-weighted average effect size of all the measures was calculated for each study.

2016, 2018). Two studies used the same participants but adopted different tasks, the average effect size of these two studies (taken as one study) were used in the analyses (Marini et al., 2016, 2018).

2.3. Data analyses

The data were analyzed using Comprehensive Meta-Analysis (version 2.0) (https://www.meta-analysis.com/); Cohen's *d* was used as the indices of effect size. We first examined the overall impairments of MTT in ASD. We then examined whether the MTT deficits in ASD were related to the following variables using moderator analyses or meta-regression: 1) verbal IQ of individuals with ASD. 2) The type of MTT (AM vs. EFT). 3) The type of task (cue word task vs. Autobiographical Memory Interview); 4) The type of outcome indices (number of details vs. specificity vs. experiential index)[2]. 5) The age period of participants (children vs. adults). 6) The male gender proportion. 7) The full IQ of individuals with ASD.

We reported the heterogeneity of the studies with the Q statistic, if the Q was significant, we adopted the random-effects model to report effect sizes; when the Q was non-significant, we adopted the fixed-effects model. The moderator analyses

[2] For number of details, we included the papers that measured MTT performance with number of details in participants' responses; in addition, papers that calculated the total score of specificity (for example, a specific event was scored 4, an extended event was scored 3, a categorized event was scored 2, a semantic associated event was scored 1, an omission was score 0, then the total score was added as the index of MTT performance) were also considered as this type (Chaput et al., 2013). For specificity, we included papers reported the proportion of specific responses or number of specific responses as MTT performances. For experiential index, we included papers reported either self-report (Crane et al., 2010) or calculated experiential index by experimenters that reference the narrative (Brown, Morris, Nida, & Baker-Ward, 2012; Crane et al., 2010) about their emotion, sensory details, vividness etc. as MTT performance.

adopted the random-effects model. All significance levels were set at $p < 0.05$ (Hedges and Vevea, 1998). Publication bias was examined with the fail-safe N analysis, which indicated the number of studies with null results needed to reject the present significant findings.

3. Results

3.1. Overall MTT impairments in individuals with ASD

The final analysis included 26 studies to compare MTT performance between 667 individuals with ASD and 671 healthy controls. Table 1 provides a summary of these studies. The mean effect size (Cohen's *d*) of MTT is -0.95, the 95% confidence interval was -0.74 to -1.17, suggesting individuals with ASD are impaired in MTT with a large effect size (see Table 2 and Fig. 2). These studies were heterogeneous (Q=78.13, $p<0.001$). Publication bias analysis revealed that at least 1571 studies with null results were needed to reject the present results, which is much larger than the number of studies included in the analysis (N=26), suggesting publication bias was not likely to contribute to the significant results.

INSERT TABLE 1 & 2 AND FIG 2 HERE

3.2. Moderator and meta-regression analyses

3.2.1. The effect of verbal ability of ASD individuals

Meta-regression analysis revealed that MTT impairments were significantly

related to verbal IQ (Z=2.07, *p*=0.038) (see Fig. 3).

INSERT FIG 3 HERE

3.2.2. The effect of the type of MTT[3]

Results indicated that the moderator effect was not significant (Q=1.47, *p*=0.226). ASD showed significant impairments in both AM (*d*=-0.98, *p*<0.001) and EFT (*d*=-0.68, *p*=0.002) (see supplementary Fig. 1). However, the number of studies on EFT was limited (N=7) and the results should be taken with caution.

3.2.3. The effect of the MTT task

There was no significant difference between the cue word task and Autobiographical Memory Interview (Q=0.73, *p*=0.390). ASD showed significant impairments in studies using both cue word task (*d*=-1.02, *p*<0.001) and Autobiographical Memory Interview (*d*=-0.81, *p*<0.001) (see supplementary Fig. 2).

3.2.4. The effect of the indices of MTT

Individuals with ASD showed similar impairments on the three indices (Q=4.17, *p*=0.125). These individuals exhibited medium to large effect sizes on all indices (number of details, *d*=-1.02, *p*<0.001; experiential index, *d*=-0.37, *p*=0.001; specificity, *d*=-0.82, *p*<0.001) (see supplementary Fig. 3).

[3] One study (Lind and Bowler, 2010) was excluded from this analysis because it did not report data on AM and EFT separately.

3.2.5. The effect of age period of ASD individuals

Individuals with ASD showed similar impairments in MTT between children and adults (Q=0.61, p=0.436). Children (d=-0.90, p<0.001) and adults (d=-1.06, p<0.001) with ASD all showed significant MTT impairments (see supplementary Fig. 4).

3.2.6. The effect of gender ratio and full IQ of ASD individuals

Meta-regression analysis revealed that MTT impairments were not predicted by gender ratio (percentage of male individuals in the ASD group) (Z=-1.22, p=0.223) or full IQ (Z=0.189, p=0.851) (see supplementary Fig. 5 & 6).

Considering the small number of studies on EFT, we made further moderator and meta-regression analyses that were limited to AM, with no change in the findings (see supplementary Table 1 and supplementary Fig. 7 - 9).

4. Discussion

The present meta-analysis revealed that individuals with ASD showed impairments in MTT with a large effect size. Moderator and meta-regression analyses showed that verbal IQ was significantly correlated with MTT impairments, the following variables did not affect the degree of impairments in MTT in individuals with ASD: type of MTT, type of task, indices of MTT, and the demographic factors including age, gender ratio, and full IQ.

4.1. Overall MTT Impairments in ASD

The present study revealed a large effect size of MTT impairments in individuals with ASD. Linguistic dysfunction of ASD individuals may contribute to MTT impairments, as our meta-regression results revealed that verbal IQ was significantly related to MTT performance. Most studies examining MTT used verbal paradigms which required participants to describe recalled or imagined scenarios (Ferri, Abel, & Brodkin, 2018; Lind, Bowler, et al., 2014). Linguistic ability is the basis for the verbal report (Ferri et al., 2018; Marini et al., 2018). Linguistic difficulty as a core symptom of individuals with ASD was manifested in different levels including microlinguistic (e.g., lexical, grammatical) and macrolinguistic (e.g. structure, discourse, narrative) (Boucher, 2012; King, Dockrell, & Stuart, 2014). In a story narrative generation task, individuals with ASD produced less grammatically complex sentences (King, Dockrell, & Stuart, 2014) and more global coherence errors and fewer new elements (Ferretti et al., 2018). Marini et al. (2018) found that impairments in MTT and story narrative generation were related in individuals with ASD. However, linguistic dysfunction could not explain all the MTT impairments. For example, Millward, Powell, Messer, and Jordan (2000) revealed non-significant correlation between MTT performance and verbal ability in individuals with ASD; individuals with ASD still showed MTT deficits compared to typically developing children after matching verbal ability (Goddard, Dritschel, & Howlin, 2014; Goddard, Dritschel, Robinson, et al., 2014). Moreover, in studies using non-verbal MTT tasks which required participants to make foresight choices instead of

describing future scenarios, individuals with ASD still demonstrated MTT difficulties (Ferri et al., 2018; Marini et al., 2016, 2018). Thus, linguistic ability seems to contribute to only part of MTT impairments in individuals with ASD.

The following factors may also contribute to the MTT impairments in ASD: executive dysfunction is likely to impact on search strategies for autobiographical memory retrieval. In the self-memory system model proposed by Conway and Pleydell-Pearce (2000), autobiographical knowledge is stored in a hierarchical structure, with lifetime periods as the top level, general events in the middle, and event-specific knowledge represented at the bottom level. When retrieving AM, one of the approaches is through generative search, which accesses the top level of memories first and then searches lower levels for more specific memories, implicating executive resources, as shown by Williams et al. (2007). This viewpoint also receives empirical support from other studies, for example, D'Argembeau, Ortoleva, Jumentier, and Van der Linden (2010) found significant correlations between executive functions and MTT specificity. Individuals with ASD have been found to show multifaceted executive dysfunction including deficits in planning, inhibition, and monitoring (Hughes, Russell, & Robbins, 1994; Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009). These impairments may cause the lack of specificity in MTT in ASD.

Individuals with ASD have “weak central coherence”, which means that they show detail-focused processing and have difficulty extracting a gist or reconstructing an intact scene (Happé and Frith, 2006). Thus, when individuals with ASD generated episodic events, they had difficulty integrating separate elements into a coherent

context and could only generate less specific events and with poorer experiential index (Bowler, Gaigg, & Lind, 2011).

Part of the MTT events were related to social communication ability, while ASD individuals had severe social impairments and lacked social experiences (Bluck, Alea, Habermas, & Rubin, 2005; Fivush, Haden, & Reese, 2006; Zamoscik, Mier, Schmidt, & Kirsch, 2016). Previous studies demonstrated that individuals with ASD had difficulty sharing the narrative in the social context and did not understand why they needed to share the memory with others (Goldman, 2008). Thus, during the task, the difficulty in sharing MTT may have contributed to the reduced specificity and fewer details in ASD individuals (Crane and Goddard, 2008).

Self-impairment deficits may be relevant. When generating MTT events, self (e.g., self-images, self-beliefs, and personal goals) plays an important role (Bennouna-Greene et al., 2012; Conway, 2005; D'Argembeau et al., 2010; Libby, Valenti, Pfent, & Eibach, 2011). Visual perspective during MTT is a phenomenological aspect of re-experiencing or pre-experiencing autobiographical events and provides a sense of self, it reflects individuals' self-attitude towards their past or future personal events (Potheegadoo, Berna, Cuervo-Lombard, & Danion, 2013). There are two types of visual perspective: field perspective and observer perspective. Field perspective refers to the egocentric reference frame whereby MTT events are viewed from the perspective of the self; while observer perspective refers to a translocation of the egocentric reference frame that one views the self from an external reference frame in MTT events (Vogeley & Fink, 2003). If a field perspective was adopted in an MTT event, the

feelings of re-experience or pre-experience were rated higher than the observer perspecitive (McDermott, Wooldridge, Rice, Berg, & Szpunar, 2016); in contrast, if an observer perspective was adopted, less vividness, fewer details, and lower emotional intensity were reported (Rice & Rubin, 2011). Individuals with ASD were found to adopt an observer perspective more often (Lind and Bowler, 2010), thus they showed less specificity and fewer details in MTT.

Poor MTT performances have been reported in various clinical populations (Bennouna-Greene et al., 2012; Berna et al., 2016; Ciaramelli et al., 2018; McDonnell, Valentino, & Diehl, 2017). The present meta-analysis included 23 studies, similar to other meta-analyses on MTT impairments in mental disorders. Berna et al. (2016) included 20 studies in a meta-analysis on AM impairments in schizophrenia patients and reported moderate to large effect size impairments (g=-0.62 to -1.40). Two meta-analyses on AM were conducted in depression with 14 and 19 studies, with results revealing that patients showed overgeneralized AM (g=1.12, d=-0.75) (Liu et al., 2013; Van Vreeswijk & De Wilde, 2004). Hallford, Austin, Takano, and Raes (2018) conducted a meta-analysis involving 19 studies on EFT in psychiatric disorders (including schizophrenia, depression, etc.), with results showing a deficit with large effect sizes in these patients (g=−0.84). These results suggested that the current findings were generally consistent with previous studies.

Regarding the underlying neural mechanisms of MTT impairments, previous studies have indicated that the core network including medial and lateral frontal cortex, posterior parietal lobe and medial temporal lobe (MTL) subsystem including

hippocampus, parahippocampus and vertromedial prefrontal cortex were related to MTT (Addis et al., 2007; Hallford et al., 2018; Schacter et al., 2007). Individuals with ASD showed abnormal structural and functional connectivity in the core network (Duerden, Mak-Fan, Taylor, & Roberts, 2012; Pua, Bowden, & Seal, 2017). These brain abnormalities might underlie the MTT impairments in ASD individuals, although further task-based neuroimaging studies are needed to examine this issue.

4.2. The effect of the type of MTT

The present results suggested that individuals with ASD showed impairments with medium to large effect size in both AM and EFT and this finding is consistent with most previous studies (Brown et al., 2012; Lind, Bowler, et al., 2014; Raffard et al., 2010). Our results showed AM and EFT were impaired to a similar degree, which is inconsistent with the study by Raffard et al. (2010) suggesting that individuals with ASD showed more serious deficits in EFT than in AM.

As to the relationship between AM and EFT, several theories have been proposed which can help to explain the impairments in individuals with ASD. Scene construction theory proposed that episodic events are coherent scenes involving individuals mentally integrating multiple information, such as semantic information and episodic details (e.g. sensory information and contextual details) into a whole spatial scene (Hassabis & Maguire, 2007). This process has no temporal direction which means scene construction is involved in both AM and EFT. If scene construction is impaired, AM and EFT should show a similar level of impairment. Consistent with scene

construction theory, Lind, Williams, et al. (2014) found that ASD showed equal impairments in non-self-relevant scenes, AM and EFT conditions. They suggested that MTT impairments in ASD could be attributed to difficulties in scene construction.

Buckner and Carroll (2007) proposed that self-projection is the ability to shift self-perspectives in the temporal, spatial, or social domain. Based on the self-projection hypothesis, AM is projecting oneself back into the past to re-experience past events and EFT is projecting oneself into the future to pre-experience possible future events (Suddendorf & Corballis, 1997). If the self-projection ability underlying MTT is impaired, AM and EFT would show similar deficits. Lind, Bowler, et al. (2014) suggested that the impairment in AM and EFT in individuals with ASD might be due to their difficulties in projecting themselves into the past or future. Projecting the self in the spatial and social domain needs to be specifically examined to test this hypothesis.

Schacter et al. (2007) proposed the constructive episodic simulation hypothesis, which suggests that EFT is based on AM, with people retrieving and recombining the elements of past events to generate EFT that might happen in the future. Based on this theory, individuals with ASD should show more severe deficits in EFT. The present meta-analysis showed that ASD individuals demonstrated similar impairments in AM and EFT, supporting the scene construction hypothesis and self-projection hypothesis but not supporting the constructive episodic simulation hypothesis. However, further studies are needed, given there were few EFT studies in the present meta-analysis.

4.3. The effect of MTT indices

Similar to Miloyan and McFarlane (2018), most of the studies on MTT used the cue word task and the Autobiographical Memory Interview. Since different tasks usually adopted different indices, i.e., the cue word task mainly used specificity, while the Autobiographical Memory Interview mainly used number of details and experiential index, we will focus our discussion on the effect of MTT indices. Our results revealed that individuals with ASD showed medium to large effect size impairments on all three main indices, with no significant difference between them. The present results suggest that the MTT deficits in individuals with ASD were universal. Similar results were also found in a meta-analysis on AM impairments in patients with schizophrenia (Berna et al., 2016).

Individuals with ASD showed similar impairments in the main indices, one possibility is these indices had similar constructs, previous studies suggested that a number of details involved memory specificity (Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002). Griffith et al. (2012) indicated that specificity and details overlap, and suggested that if participants generated less specific memories, they might retrieve fewer details. Moreover, self-reported ease of generating specific memories and details were highly correlated (Ritchie & Skowronski, 2006). We speculated that if a specific event was reported, more details would be generated at the same time, the experiential feelings might also be stronger.

4.4. The effect of age

The present meta-analysis demonstrated that both children and adults with ASD

showed large effect size impairments in MTT. Several factors might contribute to this result. Individuals with ASD showed delayed development in many aspects such as executive function which played an important role in MTT at an early stage, and these impairments continued into adulthood (Millward et al., 2000). Further, from a neuroanatomical perspective, studies have shown abnormal brain development trajectories, including decreased grey matter volume in the left inferior frontal gyrus, precuneus, and bilateral temporal lobes (Lainhart, 2015; Mak-Fan, Taylor, Roberts, & Lerch, 2012; Yu, Cheung, Chua, & McAlonan, 2011) and abnormal brain activations in the cingulate cortex and superior temporal gyrus during cognitive tasks (Herrington et al., 2007; Lee et al., 2009; Schmitz et al., 2008; Williams et al., 2006) in both children and adults with ASD. Given these are the core regions involved in MTT, longitudinal studies from childhood will help inform the development of these deficits.

4.5. The effect of gender ratio and full IQ

The present results demonstrated that MTT impairments in individuals with ASD did not correlate with gender ratio or full IQ. However, ASD is more prevalent in males (Christensen, Baio, & Braun, 2018; Ferri et al., 2018), and the limited range of gender ratio (50% to 100%) may partly explain the results. Moreover, our results were consistent with previous studies finding no gender difference in AM impairments (Bang et al., 2013; Crane et al., 2009). In contrast, Goddard, Dritschel, and Howlin (2014) found that female ASD individuals generated similar specificity of AM as healthy controls, while male ASD generated less specificity in AM. Further studies are needed

to examine this issue. The present results did not show a relationship between MTT impairments and full IQ, which might be because all studies included in the meta-analysis were conducted in high-functioning autism. Thus, further studies are needed in low to medium functioning individuals with autism.

4.6. Limitations and implications

There are several limitations in the present study. The number of studies on EFT in individuals with ASD was limited, so the results of the moderator analysis on type of MTT should be considered with caution. Further, though the moderator analyses we conducted did not show significant results, there were significant heterogeneity among the studies. That may be caused by other potential factors that we did not identify, for example, the remoteness of the events generated. Previous studies suggested that individuals with ASD reported fewer specific and less accurate AM from remote time periods than from recent time periods (Bruck et al., 2007; Goddard et al., 2014a). However, when dividing the time period into remote or recent, the criteria varied from study to study, making it difficult to conducte a moderator analysis.

Given these limitations, the present study has implications. MTT is important in daily lives, several studies have shown that strategies to improve MTT also benefited problem solving, emotion regulation, optimism, and well-being in the general population (Jing, Madore, & Schacter, 2016; Peters, Flink, Boersma, & Linton, 2010). Studies have also been conducted in clinical groups, for example, interventions such as event-specific memory training or autobiographical memory training could improve

MTT ability in schizophrenia patients (Blairy et al., 2008; Chen et al., 2017; Ricarte, Hernandez, Latorre, Danion, & Berna, 2014), could improve pleasure experience in patients with anhedonia (Favrod, Rexhaj, Nguyen, Cungi, & Bonsack, 2014), and reduce depressive symptoms in patients with depression (Vilhauer et al., 2012). MTT impairment in individuals with ASD was related to the severity of their core symptoms including restricted repetitive behaviors and reciprocal social interaction (Ciaramelli et al., 2018), theory of mind deficits (Adler, Nadler, Eviatar, & Shamay-Tsoory, 2010; Crane, Goddard, & Pring, 2011). Further studies need to explore methods to improve MTT ability in individuals with ASD and examine whether this could improve their core deficits.

4.7. Conclusion

The present meta-analysis demonstrated that individuals with ASD had severe impairments in MTT. Verbal IQ was related to MTT impairments. Furthermore, they showed similar level of impairments in AM and EFT. The MTT tasks, indices, age of participants, gender or full IQ did not affect the MTT impairments in individuals with ASD.

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Contributors

JY and YW designed the study, JY, XQ and LJ conducted literature searches, JY conducted the statistical analysis and wrote the first draft of the manuscript, JC and YW revised the manuscript extensively, CP and RC provided insightful comments to and improved the manuscript, all authors contributed to and have approved the final manuscript.

Conflict of interests

None.

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Table 1 Descriptions of studies included in the meta-analysis

Study Name	Patient Group	Control Group	Age Period	Type of MTT	Measure Paradigms	Indices	Main Findings
Adler et al., 2010	Diagnostic Criteria: ICD-10 N = 16 Mean age = 21.87 (4.75)	N = 21 Mean age = 22.90 (4.62)	Adults	AM	Interview	Experiential	The ASD group generated less specific time referrals than HC during autobiographical description.
Brown et al., 2012	Diagnostic Criteria: DSM-IV N = 30 Mean age = 9.73 (2.17) Full IQ = 104.64 (11.76)	N = 20 Mean age = 8.95 (2.35) Full IQ = 111.00 (11.53)	Children	AM	Interview	Experiential	The ASD group generated less emotional, perceptual information in memory narratives.
Bruck et al., 2007	Diagnostic Criteria: DSM-IV N = 30 Mean age = 7.60 (1.4) Full IQ = 96.00 (12.00)	N = 38 Mean age = 7.40 (1.2) Full IQ = 105 (9.5)	Children	AM	Interview	Detail	Children with ASD provided significantly fewer accurate responses on the AM events than HC.
Chaput et al., 2013	Diagnostic Criteria: ADI-R, ADOS, ASDI N = 15 Mean age = 19.30 (6.10) Full IQ = 103.50 (12.90) Verbal IQ = 109.00 (17.40)	N = 15 Mean age = 20.90 (6.50) Full IQ = 109.20 (16.40) Verbal IQ = 120.60 (19.70)	Children and Adults	AM	Interview	Detail	Individuals with ASD generated fewer episodic memories and with fewer details about emotional and sensory feelings.
Ciarameli et al., 2018	Diagnostic Criteria: DSM-5/ADI-R/ADOS-2 N = 14 Mean age = 11.00 (0.67) Full IQ = 108.79 (4.17)	N = 15 Mean age = 11.87 (0.58) Full IQ = 118.15 (1.99)	Children	EFT AM	Interview	Detail	Compared with HC, individuals with ASD produced fewer internal details but a similar number of external details during AM and EFT.
Crane et al., 2008	Diagnostic Criteria: Formal diagnosis by a clinical psychologist or psychiatrist N = 14 Mean age = 37.87 (12.63) Full IQ = 114.33 (14.39) Verbal IQ = 110.87 (16.86)	N = 15 Mean age = 32.73 (17.54) Full IQ = 111.00 (15.83) Verbal IQ = 106.53 (15.03)	Adults	AM	Interview	Detail	Individuals with ASD recalled fewer specific details in the episodic memory narrative than HC.

Crane et al., 2009	Diagnostic Criteria: DSM-IV/ICD-10 N = 28 Mean age = 41.57 (16.49) Full IQ = 117.18 (13.47) Verbal IQ = 115.39 (12.10)	N = 28 Mean age = 40.53 (17.20) Full IQ = 115.11 (11.67) Verbal IQ = 110.68 (13.35)	Adults	AM	Cue word	Specificity	Individuals with ASD showed deficits in AM, they generated fewer proportion of specific AM than HC and individuals with ASD took longer time to generate AM.
Crane et al., 2010	Diagnostic Criteria: DSM-IV/ICD-10 N = 20 Mean age = 36.55 (11.62) Full IQ = 113.00 (13.69) Verbal IQ = 114.20 (12.27)	N = 20 Mean age = 35.45 (11.75) Full IQ = 112.50 (8.85) Verbal IQ = 111.05 (10.70)	Adults	AM	Interview	Experiential, Specificity	Adults with ASD generated fewer specific memories than HC, but no significant difference in emotional details or sensory elements.
Crane et al., 2011	Diagnostic Criteria: DSM-IV/ICD-10 N = 28 Mean age = 41.57 (16.49) Full IQ = 117.18 (13.47) Verbal IQ = 115.39 (12.10)	N = 28 Mean age = 40.53 (17.20) Full IQ = 115.11 (11.67) Verbal IQ = 110.68 (13.35)	Adults	AM	Cue word	Specificity	Individuals with ASD generated fewer specific memories than HC, but more categoric memories than HC.
Crane et al., 2012	Diagnostic Criteria: DSM-IV/ICD-10 N = 18 Mean age = 37.17 (13.59) Full IQ = 114.00 (13.26) Verbal IQ = 115.11 (9.07)	N = 18 Mean age = 37.00 (14.04) Full IQ = 117.39 (8.22) Verbal IQ = 116.39 (7.48)	Adults	AM	Cue word	Specificity	Adults with ASD generated similar specific memories with HC but took significantly longer time to retrieve.
Crane et al., 2013	Diagnostic Criteria: ADOS-G N = 18 Mean age = 40.12 (13.94) Full IQ = 107.81 (10.30) Verbal IQ = 109.94 (19.14)	N = 18 Mean age = 44.80 (11.59) Full IQ = 110.27 (15.72) Verbal IQ = 111.72 (14.48)	Adults	EFT AM	Interview	Specificity	Adults with ASD performed at an equivalent level to HC when generating both past and future events, participants (including ASD and HC) generated more specific events and fewer semantic events during AM than EFT.
Goddard et al., 2007	Diagnostic Criteria: Formal diagnosis by a clinical psychologist or psychiatrist N = 37	N = 39	Adults	AM	Cue word	Specificity	Individuals with ASD generated fewer specific AM and also took significantly longer time to retrieve.

	Mean age = 25.3 (6.51) Full IQ = 97.59 (17.48) Verbal IQ = 98.27 (18.53)	Mean age = 21.26 (3.23) Full IQ = 99.44 (18.37) Verbal IQ = 98.15(20.45)					
Goddard et al., 2014a	Diagnostic Criteria: DSM-IV N = 63 Full IQ = 103.60 (13.08)	N = 63 Full IQ = 104.76 (11.79)	Children	AM	Cue word Interview	Experiential, Specificity	Individuals with ASD retrieved significantly fewer specific memories and required more prompting.
Goddard et al., 2014b	Diagnostic Criteria: DSM-IV N = 24 Full IQ = 105.90 (12.80)	N = 24 Full IQ = 106.30 (10.80)	Children	AM	Cue word Interview	Specificity	Individuals with ASD retrieved poorer specificity of AM than HC; females reported more emotional memories than males.
Hanson et al., 2013	Diagnostic Criteria: DSM-IV N = 25 Full IQ = 85.71 (21.00)	N = 25 Full IQ = 109.12 (8.03)	Children	EFT	Cue word	Detail	Children with ASD showed impairments in future self thinking.
Kristen et al., 2014	Diagnostic Criteria: ICD-10 N = 20 Mean age = 28.25 (11.57) Verbal IQ = 105.20 (15.61)	N = 20 Mean age = 29.30 (11.12) Verbal IQ = 105.00 (7.720)	Adults	AM	Interview	Detail	Individuals with ASD generated significantly fewer AM and semantic memory than HC across four lifetime periods (pre-school, primary school, secondary school, post-school).
Lind et al., 2010	Diagnostic Criteria: ADOS N = 14 Mean age = 41.38 (12.71) Full IQ = 105.86 (14.52) Verbal IQ = 107.86 (12.37)	N = 14 Mean age = 43.83 (10.39) Full IQ = 108.57 (18.20) Verbal IQ = 110.71 (15.75)	Adults	EFT AM	Interview	Experiential, Specificity	Individuals with ASD generated fewer AM and EFT than HC. Compared with HC, individuals with ASD prefer observer perspective than field perspective when reporting MTT.
Lind et al., 2014	Diagnostic Criteria: ADOS-G, ADI-R N = 20 Mean age = 8.67 (1.37) Full IQ = 105.65 (16.34) Verbal IQ = 104.05 (13.54)	N = 20 Mean age = 8.32 (0.91) Full IQ = 109.05 (8.68) Verbal IQ = 107.15 (5.29)	Children	EFT AM	Interview	Specificity	Children with ASD reported poorer specificity in AM and EFT than HC.
Losh et al., 2003	Diagnostic Criteria: DSM-IV/ICD-10 N = 28 Mean age = 11.30 (2.50) Verbal IQ = 103.80 (16.10)	N = 22 Mean age = 10.60 (1.10) Verbal IQ = 107.00 (8.90)	Children	AM	Interview	Detail	Individuals with ASD showed difficulty in personal narratives including less complex syntax, poor structure and need more prompts.
	Diagnostic Criteria: ADI-R		Children	AM	Cue word	Detail	

Maister et al., 2013	N = 14 Mean age = 12.20 (0.60) Verbal IQ = 109.50 (13.70)	N = 14 Mean age = 12.10 (0.20) Verbal IQ = 120.60 (19.70)					Children with ASD recalled fewer AM details and more general details compared with HC.
Marini et al., 2016	Diagnostic Criteria: ADOS-2 N = 77 Mean age = 8.11 (1.51) Full IQ = 106.08 (14.13)	N = 77 Mean age = 8.23 (11.41) Full IQ = 106.32 (11.41)	Children	EFT	Ernie's doggies' task (Nonverbal)		Children with ASD showed EFT impairments, the impairments not only related to self-projection, but also rely on other abilities.
Marini et al., 2018	Diagnostic Criteria: ADOS-2 N = 77 Mean age = 8.11 (1.51) Full IQ = 106.08 (14.13)	N = 77 Mean age = 8.23 (11.41) Full IQ = 106.32 (11.41)	Children	EFT	Picture Book Trip task (Nonverbal)		Part of children with ASD showed EFT deficit and EFT was related with narrative generation.
Millward et al., 2000	Diagnostic Criteria: DSM-III N = 12	N = 12	Children	AM	Cue word	Detail	Children with ASD showed poorer performance in AM, no difference was found in memory related with others compared with HC.
Robinson et al., 2017	Diagnostic Criteria: DSM-IV N = 24 Full IQ = 103.63 (9.90)	N = 24 Full IQ = 104.25 (11.84)	Children	AM	Cue word	Specificity, Detail	Individuals with ASD generated AM with less emotional and sensory information, but the specificity did not show difference compared with HC.
Tanweer et al., 2010	Diagnostic Criteria: DSM-IV N = 11 Mean age = 34.10 (11.10) Full IQ = 112.64 (8.76) Verbal IQ = 109.55 (11.26)	N = 15 Mean age = 32.70 (9.50) Full IQ = 110.68 (8.94) Verbal IQ = 108.47 (10.99)	Adult	AM	Interview	Specificity	Individuals with ASD recalled fewer memories and also poorer specificity in AM.
Terretti et al.,2018	Diagnostic Criteria: ADOS-2 N = 66 Mean age = 8.14 (1.51) Full IQ = 106.06 (14.34)	N = 66 Mean age = 8.23 (1.51) Full IQ = 105.91 (10.95)	Children	EFT	Picture Book Trip task (Nonverbal)		Part of children with ASD showed MTT impairments and these individuals also had worse performance in narrative generation.

Note: ADI-R = Autism Diagnostic Interview-Revised; ADOS = Autism Diagnostic Observation Schedule; ADOS-G = Autism Diagnostic Observation Schedule-Generic; ADOS-2 = Autism Diagnostic Observation Schedule-2nd edition; AM = Autobiographical memories; ASD = autism spectrum disorders; ASDI = Asperger Syndrome Diagnostic Interview; DSM = Diagnostic Statistical Manual; EFT = episodic future thinking; HC = healthy controls; ICD= International Classification of Diseases; MTT = mental time travel.

Table 2 MTT impairments in individuals in ASD

		k	N-ASD	N-HC	*d*	Z	*p*	95%CI	Q	*p*	Fail-safe N
MTT impairments in individuals with ASD	All	25	667	671	-0.957	-8.73	< 0.001	(-1.17, -0.74)	78.13	< 0.001	1571
Type of MTT											
	AM	22	499	503	-0.978	-7.71	< 0.001	(-1.23, -0.73)			1050
	EFT	7	234	235	-0.675	-3.12	0.002	(-1.10,-0.25)			86
	Total between								1.47	0.226	
Task on MTT											
	Cue Word	10	273	275	-1.015	-5.56	< 0.001	(-1.37, -0.66)			275
	Interview	15	338	340	-0.812	-5.33	< 0.001	(-1.11, -0.51)			334
	Total between								0.73	0.390	
Type of indices of MTT											
	Detail	11	211	215	-1.019	-5.68	< 0.001	(-1.37, -0.68)			248
	Experiential Index	6	157	152	-0.370	-3.20	0.001	(-0.58, -0.14)			12
	Specificity	13	329	335	-0.822	-5.19	< 0.001	(-1.13, -0.51)			295
	Total between								4.17	0.125	
Age period of participants											
	Adults	11	225	236	-1.062	-6.04	< 0.001	(-1.41, -0.72)			284
	Children	13	427	420	-0.897	-12.36	< 0.001	(-1.04, -0.76)			450
	Total between								0.61	0.436	

Note. *k* = number of studies; N-ASD = number of individuals with autism spectrum disorders; N-HC = number of healthy controls; *d* = Cohen's *d*; 95% CI = 95% confidence interval (Lower CI, Upper CI).

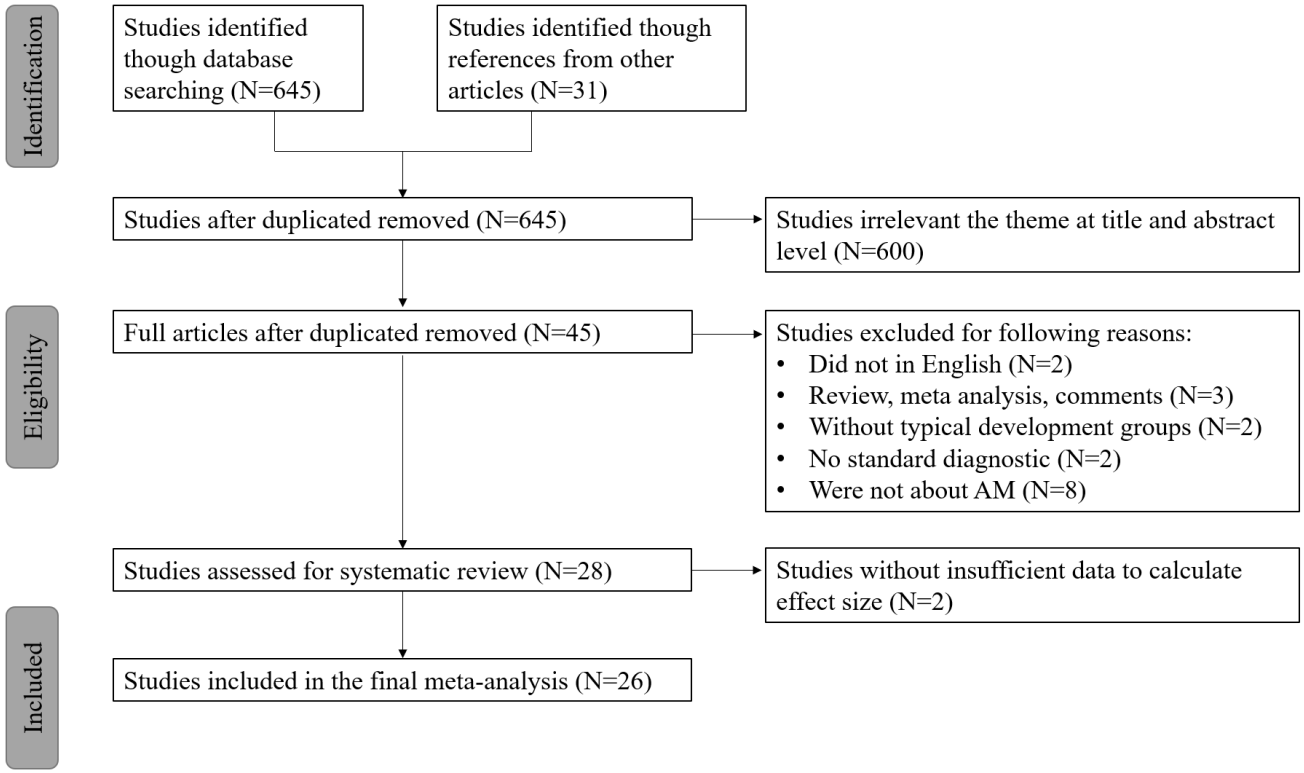


Fig. 1 Flow diagram of the article selection.

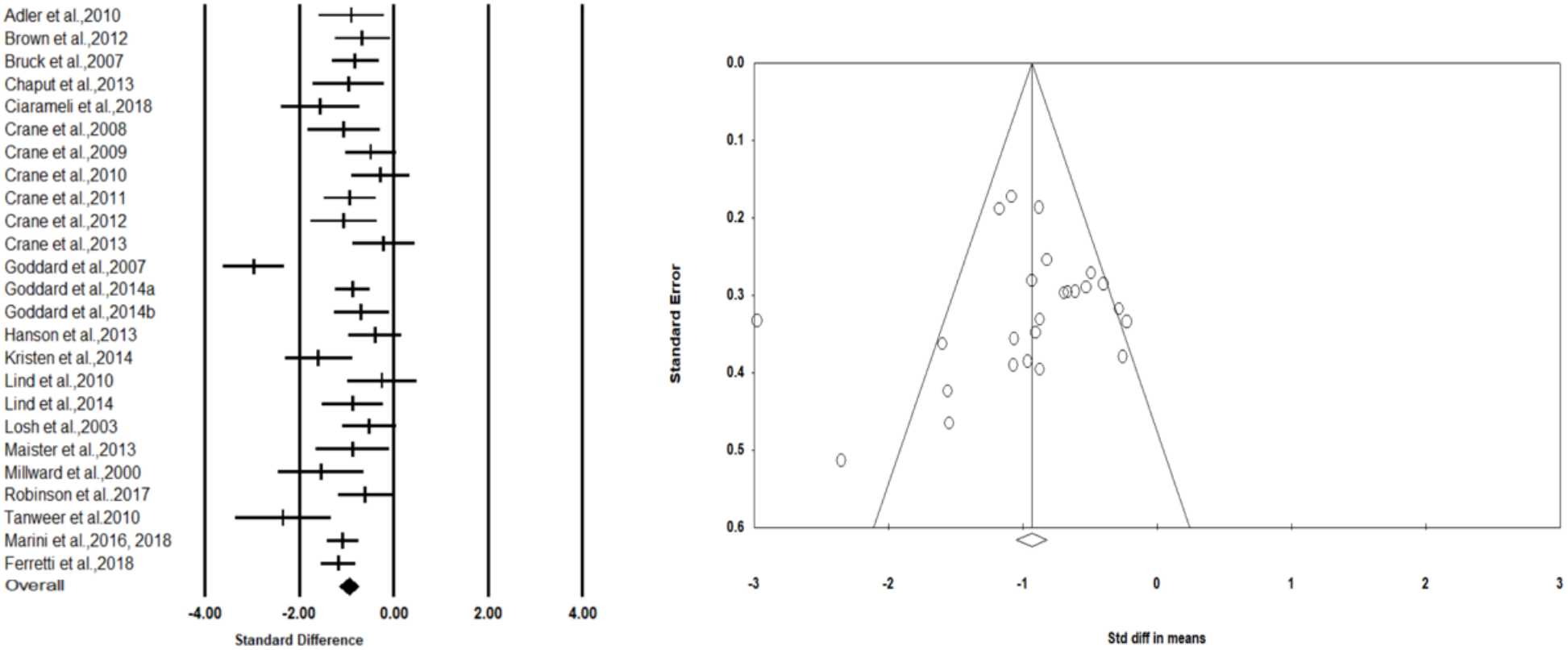


Fig. 2 Forest plot (left panel) and funnel plot (right panel) of the overall MTT impairments in individuals with ASD. The plots display the effect size with the associated 95% confidence intervals (left panel).

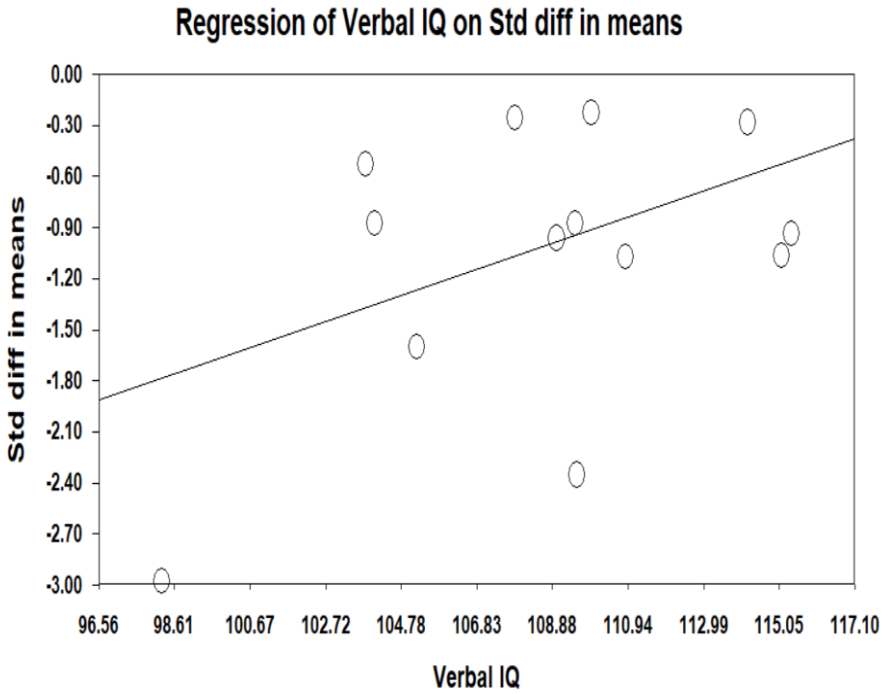
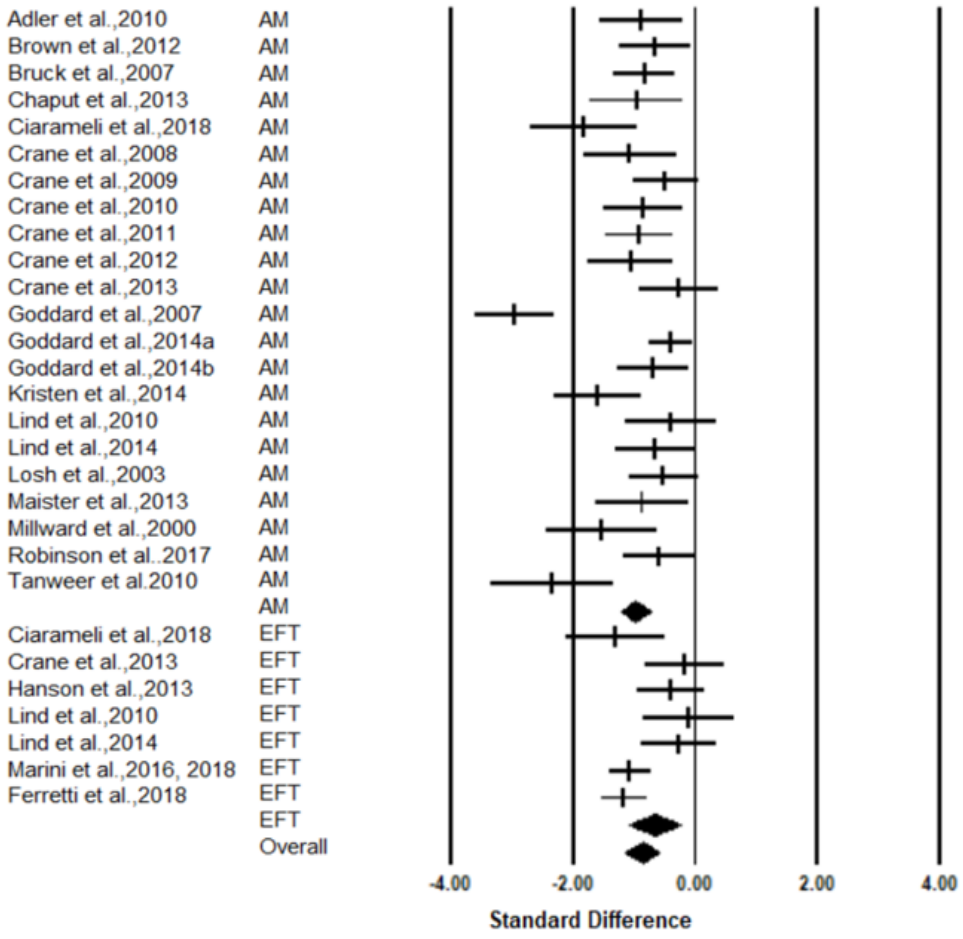
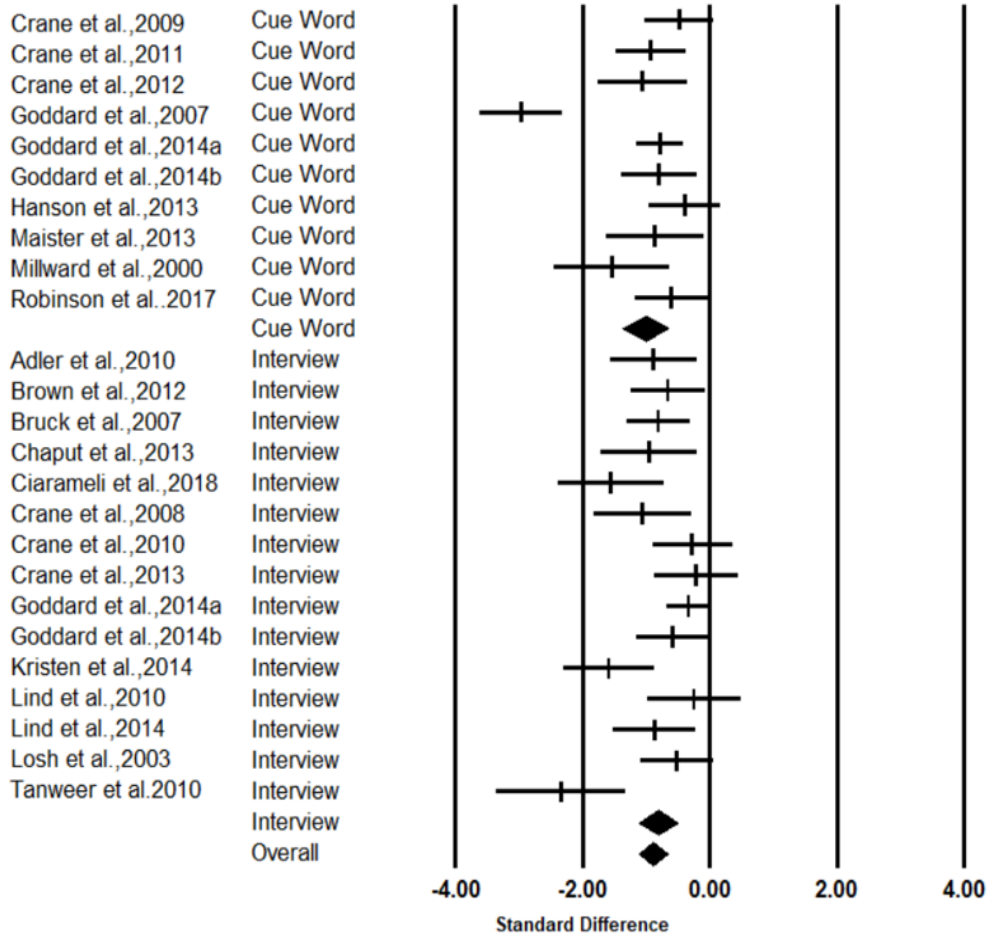


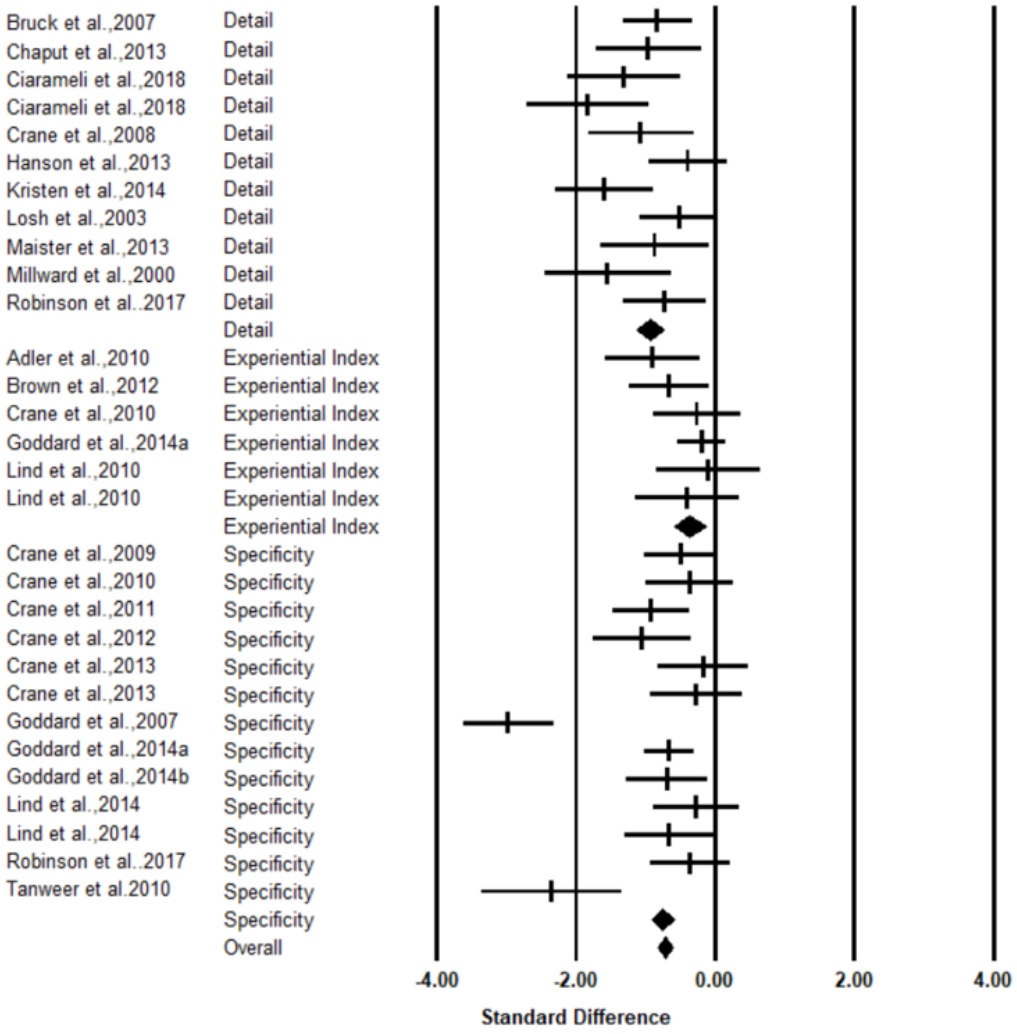
Fig. 3 Meta-regression of verbal IQ predicting MTT impairments in individuals with ASD.



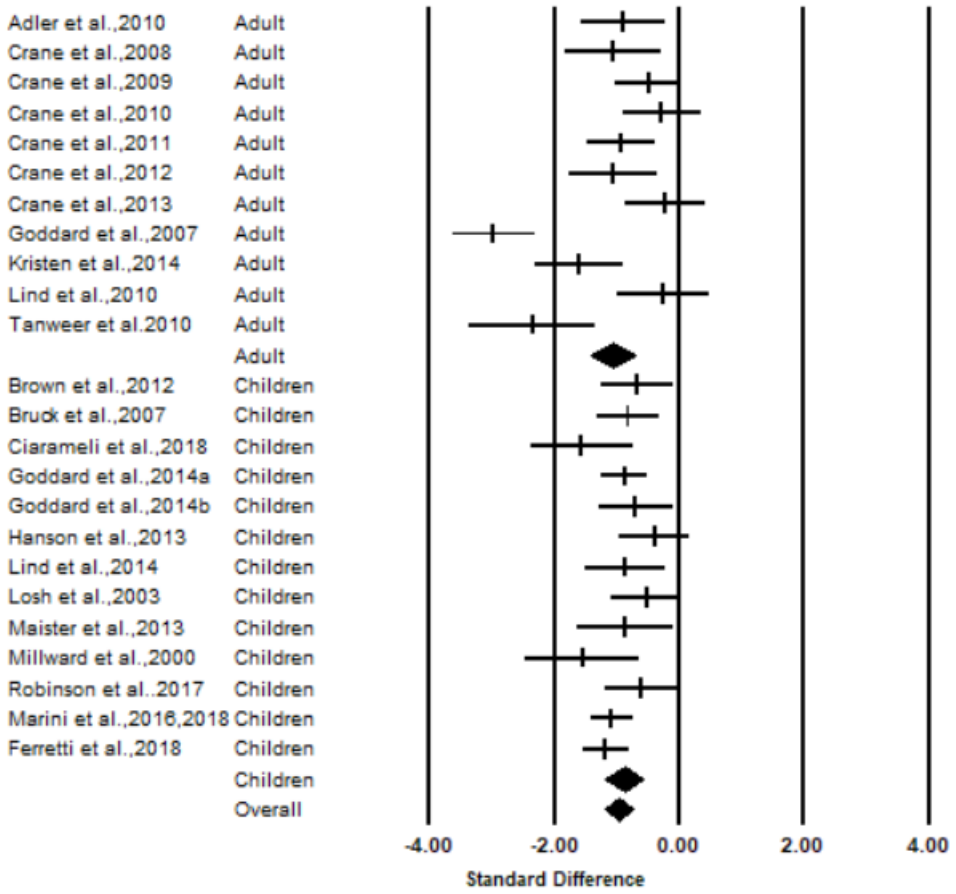
Supplementary Fig. 1 Forest plot of the effect of the type of MTT impairments in individuals with ASD. The plots display the effect size with the associated 95% confidence intervals.



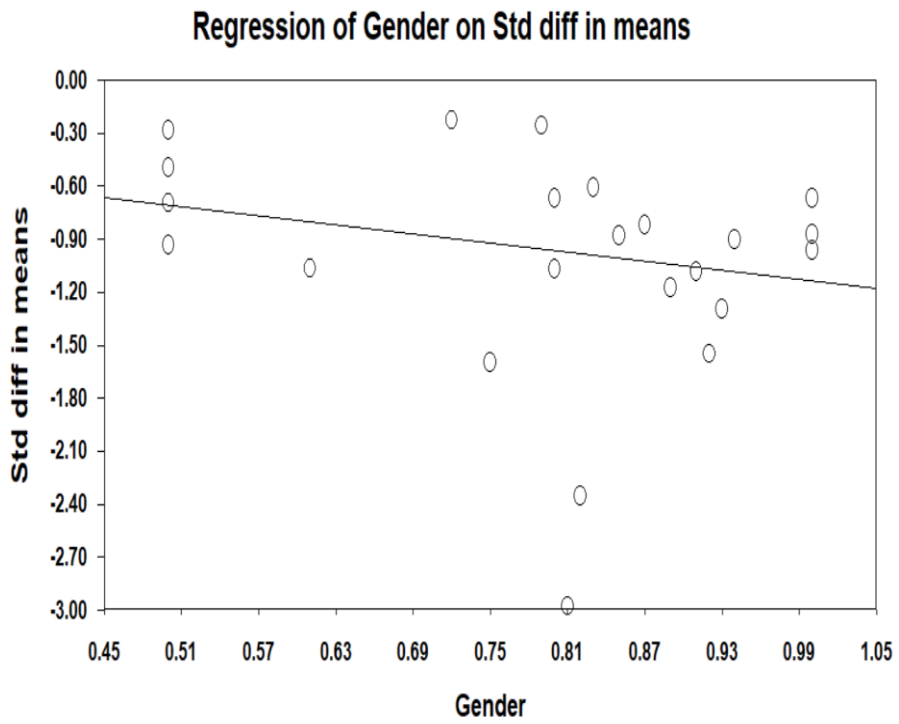
Supplementary Fig. 2 Forest plot of the effect of the task on MTT impairments in individuals with ASD. The plots display the effect size with the associated 95% confidence intervals.



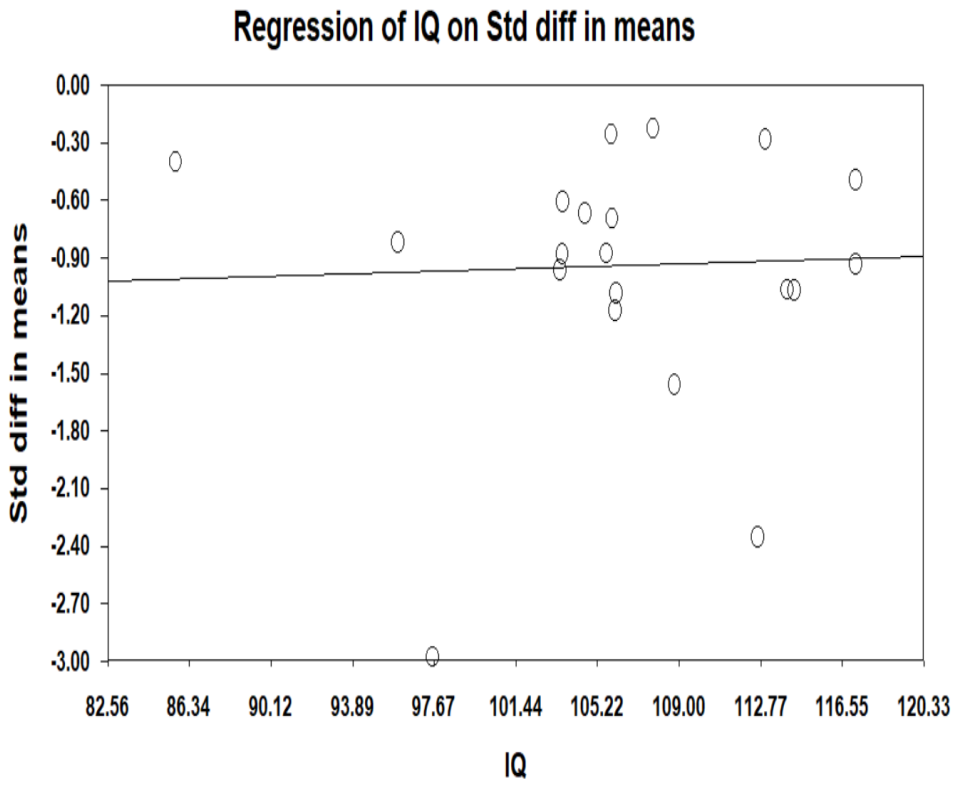
Supplementary Fig. 3 Forest plot of the effect of the indices of MTT impairments in individuals with ASD. The plots display the effect size with the associated 95% confidence intervals.



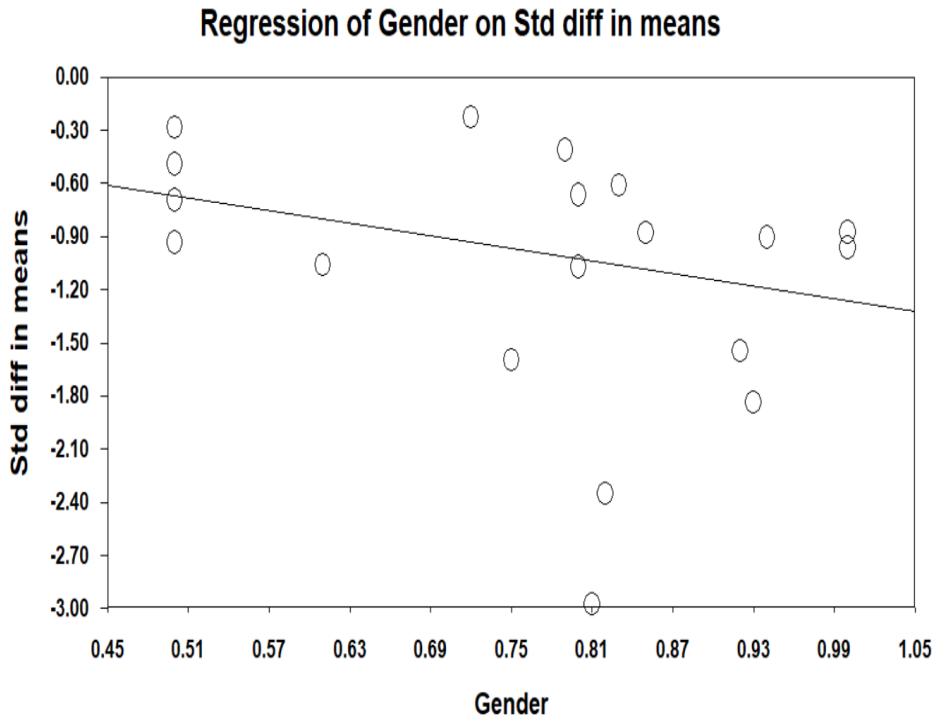
Supplementary Fig. 4 Forest plot of the effect of the age period of MTT impairments in individuals with ASD. The plots display the effect size with the associated 95% confidence intervals.



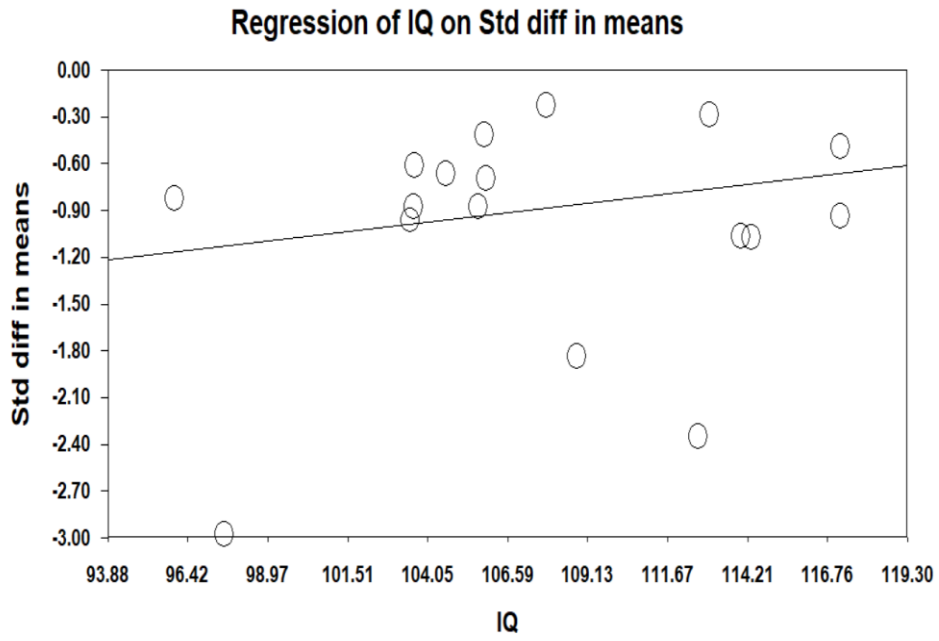
Supplementary Fig. 5. Meta-regression of gender ratio predicting MTT impairments in individuals with ASD.



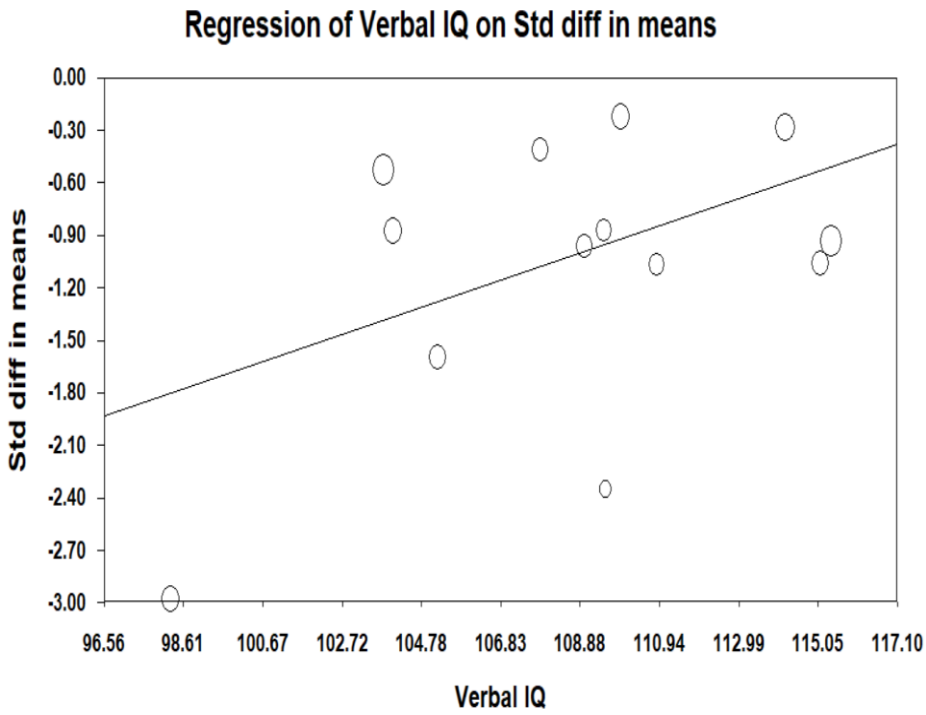
Supplementary Fig. 6. Meta-regression of IQ predicting MTT impairments in individuals with ASD.



Supplementary Fig. 7. Meta-regression of gender ratio predicting AM impairments in individuals with ASD.



Supplementary Fig. 8. Meta-regression of IQ predicting AM impairments in individuals with ASD.



Supplementary Fig. 9. Meta-regression of verbal IQ predicting AM impairments in individuals with ASD.

Supplement Table. 1. AM impairment in individuals in ASD

		k	N-ASD	N-HC	*d*	Z	*p*	95%CI	Q	*p*	Fail-safe N
MTT impairment in individuals with ASD	All	22	409	503	-0.977	-7.52	< 0.001	(-1.23, -0.72)	73.47	< 0.001	1067
Task on MTT											
	Cue Word	9	248	250	-1.082	-5.53	< 0.001	(-1.47, -0.70)			249
	Interview	15	338	340	-0.823	-5.33	< 0.001	(-1.13, -0.52)			339
	Total between								1.08	0.298	
Type of indexes of MTT											
	Detail	9	172	175	-1.012	-8.78	< 0.001	(-1.24 -0.79)			184
	Experiential Index	6	167	162	-0.393	-3.51	< 0.001	(-0.61, -0.17)			16
	Specificity	10	267	273	-0.987	-5.45	< 0.001	(-1.34, -0.63)			252
	Total between								4.76	0.093	
Age period of participants											
	Adult	11	225	236	-1.086	-5.67	< 0.001	(-1.46, -0.71)			293
	Children	10	259	252	-0.815	-8.74	< 0.001	(-0.98, -0.63)			194
	Total between								0.64	0.425	

Note: *k* = number of studies; N-ASD = number of individuals with autism spectrum disorders; N-HC = number of healthy controls; *d* = Cohen's d; 95% CI = 95% confidence interval (Lower CI, Upper CI); The overall effect size was calculated using a random effect model.